

**National Laboratory Field Work Proposal  
Annual Progress Report**

**Project Title:** Development of Stronger and More Reliable Cast Austenitic Stainless Steels (H-Series) Based on Scientific Design Methodology

**Covering Period:** September 30, 2002 through September 29, 2003

**Date of Report:** October 28, 2003

**Recipient:** Duraloy Technologies, Inc.  
120 Bridge Street, Scottsdale, PA 15683-0081

**Award Number:** DE-FC07-01ID14245

**Subcontractors:** None

**Other Partners:** See attached Table 1

**Contact(s):** See attached Table 1

**Project Team:** Sara A. Dillich, DOE-HQ contact; See attached Table 1 for industry contacts.

**Project Objective:** The H-Series austenitic steels (HK, HP, and micro-alloyed HP) are used extensively in several industries for a broad range of high-temperature applications. The applications include radiant burner tubes and transfer rolls in heat-treating furnaces and in secondary processing of steel, coiler drums and rolls of Steckel mills used in steel processing, tubes used for ethylene production in chemical industry, and many others. The H-Series stainless steels had evolved over the last 80 years and have reached the saturation levels in both their mechanical properties and the upper use temperature.

The goal of the proposed program is to increase the high-temperature strength by 50% and upper use temperature by 30 to 60°C (HP mod., 100 to 200°C for mod. HK) for H-Series of cast austenitic stainless steels. Industrial implementations of the advanced steels from this project will result in an energy savings of 38 trillion BTU/year. The program goal will be achieved by the use of alloy design methods developed at the Oak Ridge National Laboratory (ORNL), based on precise micro-characterization and identification of critical microstructure/properties relationships, and on combining them with the modern computational science-based tools that calculate phases, phase fractions, and phase

compositions based on alloy compositions. The combined approach of micro-characterization of phases and computational phase prediction will permit rapid improvement of a current alloy composition with long-term benefit of customizing alloys within grades for specific applications.

**Background:**

Heat-resistant cast austenitic stainless steels and alloys are the backbone of the chemical, petrochemical, heat-treating and metals processing industries today, with all applications continuing to drive performance, durability and use-temperatures higher, while economics tries to force the cost of such alloys lower. For service temperatures above 850 to 900°C, the dominant alloys are HK-40 stainless steels or the modified or micro-alloyed HP stainless alloys. The Alloy Casting Institute introduced the classifications used today in 1941, designating the heat-resistant grades as H-grades and the corrosion-resistant stainless steels and alloys as C-grades. The HK-40 stainless steel is essentially a Fe-25Cr-20Ni-0.4C alloy, whereas HP-40 stainless alloy is Fe-25Cr-35Ni-0.4C, with more creep-resistant modifications being the HP modified (+Nb) or the HP micro-alloyed (+Nb+Ti or +Nb+Zr) materials. In the 1960s and 1970s, efforts to improve the carburization-resistance of the HK-40 steels led to additions of up to 2% Si and increases in Ni (IN-519, 25Cr-25Ni-1.5Nb and HP alloys), while efforts to increase the strength and creep-resistance added Nb [1,4]. Costly upgrades of the modified HP alloys include additions of W and Co to further increase the high-temperature strength.

Alloy development of complex engineering alloys based on single or multiple alloying element additions or changes over wide ranges can often be very labor intensive, time consuming and costly. Usually such traditional brute-force efforts produce only modest incremental improvements, and then such improvements must be further verified by testing relevant to real-time component service. This proposal uses the following three concepts:

Concept 1 – Conduct computational thermodynamic and kinetic modeling to identify the phases present in the virgin cast compositions of an HK and modified HP. The same analysis will also be carried out on cast samples subjected to controlled thermal exposure in the laboratory and after service operating conditions.

Concept 2 – Conduct microcharacterization of the phases present and identification of critical microstructure/property relationship for the virgin and exposed samples of HK and modified HP alloys. The outcome of this analysis will result in (a) verification of the phases predicted by the computational modeling and (b) identification of expected properties that will be verified with the observed properties, and (c) development of new

compositions for higher strength versions of the HK and modified HP alloy.

Concept 3 – Prepare experimental size cast alloys of the higher strength compositions designed from Concepts 1 and 2 above. Characterize the compositions for mechanical properties and thermal exposure and compare with the predicted phases and properties.

**Status:**

ThermoCalc™ modeling was used to predict the stable phases that were expected in selected creep-tested specimens of HP alloy from Duralloy. SEM and TEM analyses of the samples were carried out to quantify various phases in the creep-tested specimens. The microstructural analysis data matched extremely well with the predicted results, thus giving confidence that ThermoCalc™-based analysis can be used to control the desired levels of phases in HP-grade of steel.

ThermoCalc™ analysis was used to systematically determine the effect of alloying elements such as Mo, W, Nb, Ti, etc. on the stability of carbide phases at temperatures in the range of 2000 to 2200°F. Very interesting results have emerged with the potential of developing alloy compositions with use temperatures of 50 to 100°F higher than the current HP compositions.

Experimental alloys of 20 lb were melted and cast into slabs at ORNL. Creep tests on samples from these heats are being used to validate the ThermoCalc™ predictions. Initial creep results at 2200°F are confirming the predicted trends.

Creep data from literature and experimental heats were carried out to develop correlations with volume percent of carbide phases.

**Plans for Next Year:**

1. Continue creep testing on experimental heats to validate the ThermoCalc™ predictions.
2. Cast large heats (500 to 1000 lb) into centrifugal cast tubes for creep testing and compare the results with the laboratory size heats.
3. Initiate developing the neural network model for incorporating creep predicting capability based on composition.

**Patents:**

None

**Milestone Status Table:**

<b>ID Number</b>	<b>Task / Milestone Description</b>	<b>Planned Completion</b>	<b>Actual Completion</b>	<b>Comments</b>
<b>1</b>	<b>Computational Thermodynamic Analysis of Various Phases in HK and HP Modified Steel</b>	10/31/04		
1.1	ThermoCalc™ analysis of phases for current HK and HP modified compositions in the cast, aged, and removed from service conditions	4/30/03		
1.2	ThermoCalc™ analysis of newly identified modifications of HK and HP modified compositions in the cast and aged conditions	10/31/04		
1.3	Refining the ThermoCalc™ analysis to incorporate the cooling rates observed during the centrifugal and static castings	10/31/04		
<b>2</b>	<b>Micro-characterization of Specimens of HK and HP Modified for Verification of Computational Models and Correlation with Mechanical Properties</b>	4/30/04		
2.1	Micro-characterization analysis for current HK and HP modified compositions in the cast, aged, and removed from service conditions	10/31/03		
2.2	Correlate the microstructural analysis with mechanical properties	1/31/03	1/31/03	
2.3	Identify new compositions of improved strength and thermal stability based on verified computational analysis and microstructural/mechanical property correlation	3/31/04		

<b>ID Number</b>	<b>Task / Milestone Description</b>	<b>Planned Completion</b>	<b>Actual Completion</b>	<b>Comments</b>
<b>3</b>	<b>Cast Experimental Size Heats of New Compositions Developed Based on Tasks 1 and 2 and Determine Their Mechanical Properties</b>	1/31/05		
3.1	Melt 20-lb-size heats and cast into 1 × 4 × 6-in. slabs	4/30/03	4/30/03	
3.2	Conduct stress relaxation tests on cast compositions	10/31/03		
3.3	Conduct detailed mechanical properties testing of selected compositions	4/30/04		
3.4	Correlate mechanical properties with microstructure	1/31/05		
<b>4</b>	<b>Centrifugal and Static Casting of Selected Compositions</b>	2/28/05		
4.1	Melt 500-lb-size heats and make centrifugal and static castings	7/31/04		
4.2	Conduct mechanical properties on centrifugal and static castings poured from 500-lb-size heats	2/28/05		
<b>5</b>	<b>Develop an Alloy Property/Composition Predicting Software Tool for Commercial Applications</b>	2/28/05		
5.1	Develop all correlation of properties with microstructural features and the alloy compositions	7/31/04		
5.2	Develop user-friendly software that captures the property/composition correlation for H-Series stainless steels with predicting capabilities	2/28/05		
<b>6</b>	<b>Fabricate Prototype Components</b>	3/31/05		
6.1	Cast tubes and other accessories needed to fabricate prototype components	7/31/04		

<b>ID Number</b>	<b>Task / Milestone Description</b>	<b>Planned Completion</b>	<b>Actual Completion</b>	<b>Comments</b>
6.2	Fabricate prototype components through machining and welding operations	10/31/04		
6.3	Complete installation of the prototype components in various productions applications	3/31/05		
<b>7</b>	<b>Meetings and Technical Reports</b>	3/31/05		
7.1	Hold at least two technical meetings per year	3/31/05		
7.2	Complete final report	3/31/05		

**Budget Data** (as of 9/29/03): The approved spending should not change from quarter to quarter. The actual spending should reflect the money actually spent on the project in the corresponding periods.

<b>Phase/Budget Period</b>			<b>Approved Spending Plan</b>			<b>Actual Spent to Date</b>		
<b>Year</b>	<b>From</b>	<b>To</b>	<b>DOE Amount</b>	<b>Cost Share</b>	<b>Total</b>	<b>DOE Amount</b>	<b>Cost Share</b>	<b>Total</b>
1	9/01/01	9/29/02	300,000	308,500	608,500	37,573	80,000	117,573
2	9/30/02	9/29/03	300,000	308,500	608,500	276,928	266,000	542,928
3								
<b>Totals:</b>			<b>600,000</b>	<b>617,000</b>	<b>1,217,000</b>	<b>314,501</b>	<b>346,000</b>	<b>660,501</b>

**Cost Share Last Quarter:**

Duraloy: \$50,000

**Spending Plan for the Next Year:**

FY 2004 Month	Estimated Spending		
	DOE Funds	Cost Share	Total
October	18,555	54,000	72,555
November	18,555	54,000	72,555
December	18,555	54,000	72,555
January	50,000	40,000	90,000
February	50,000	40,000	90,000
March	50,000	50,000	100,000
April	50,000	50,000	100,000
May	50,000	50,000	100,000
June	50,000	50,000	100,000
July	50,000	50,000	100,000
August	50,000	50,000	100,000
September	50,000	50,000	100,000
Total:	505,665	592,000	1,097,665

**Table 1. Key Organizations, Investigators, Contact Information, and Responsibilities**

Organization	Investigator	Contact Information	Responsibilities
Duraloy Technologies Inc.	Roman Pankiw	(724) 887-5100 Ext. 188 Fax: 887-5224 <a href="mailto:techmgr@duraloy.com">techmgr@duraloy.com</a>	Overall project responsibility, alloy and property identification, casting trials, prototype assembly manufacturing, and customer interface
Bethlehem Steel Corporation	Tony Martocci	(610) 694-6657 Fax: 694-1658 <a href="mailto:martocci@bethsteel.com">martocci@bethsteel.com</a>	Identify applications, provide details of sizes needed, and implement prototypes in production conditions
The Timken Company	Mark F. Carlson	(330) 471-3809 Fax: 471-2644 <a href="mailto:Carlson@timken.com">Carlson@timken.com</a>	Identify applications, property needs, size needs, and implement prototypes in production conditions
Energy Industries of Ohio	Bob Purgert	(216) 533-1309 Fax: 398-9969 <a href="mailto:Purgert@msn.com">Purgert@msn.com</a>	Represents the alloy property needs of the chemical, steel, and heat treating industries of Ohio; assist in identifying components for each industry and implementing various solutions
Harper International	William Helfrich	(716) 684-7400 Fax: 684-7405	Provide design and location for installing prototype components; implement installation of components in Harper's designed production systems
IPSCO	Laurie Collins	(306) 924-7377 Fax: <a href="mailto:LCOLLINS@ipSCO.com">LCOLLINS@ipSCO.com</a>	Input on detailed analysis of issues with the use of H-Series for current application and assist in solution implementation
NUCOR Steel Corporation	Robert Bennett	() Fax: (219) 922-8039	Provide input on design specifications and locations for installation of prototypes, installing assemblies in production conditions, and inspect furnaces
Oak Ridge National Laboratory	Vinod Sikka	(865) 574-5112 Fax: 574-4357 <a href="mailto:sikkavk@ornl.gov">sikkavk@ornl.gov</a>	Project coordination at ORNL, preparation of experimental alloys and mechanical testing.
	Philip Maziasz	(865) 574-5082 Fax: 574-4357 <a href="mailto:maziaszpj@ornl.gov">maziaszpj@ornl.gov</a>	Microcharacterization of phases and alloy design.
	Suresh Babu	(865) 574-4806 Fax: 574-4928 <a href="mailto:babuss@ornl.gov">babuss@ornl.gov</a>	Computational phase analysis